# Interpretable Network Traffic Classification by Integrating Human Expertise with Machine Learning

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Information Visualization and Visual Analytics (IVA)

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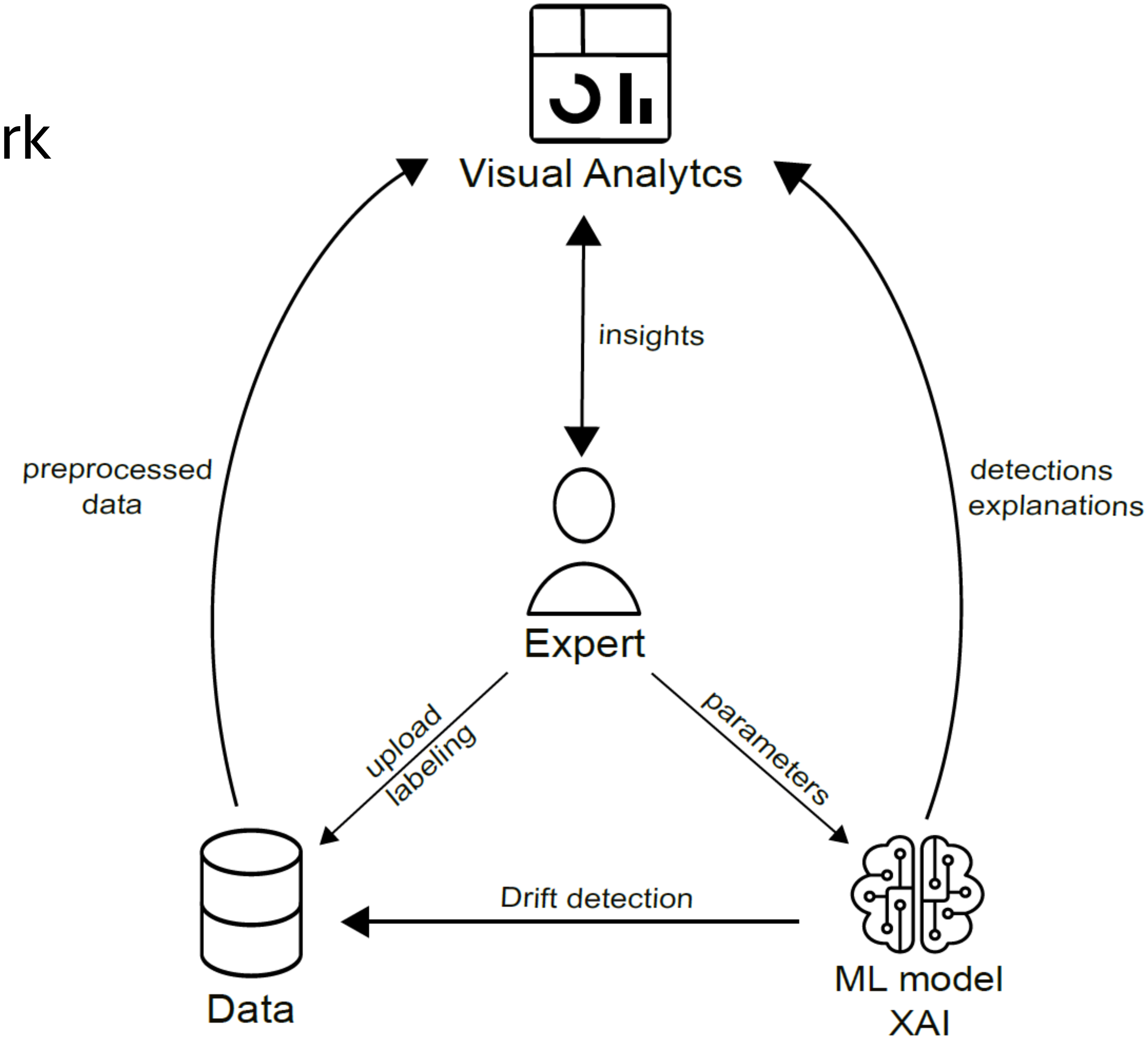
# Motivation

- Current situation with ML models
  - Learn hidden relationships in data
  - Excellent performance classification and anomaly detection
- Our goals in fusion with VA:
  - Classification alone is not enough (lacking trust, validation, and understanding)
  - Leverage machine learning for valuable insights
  - Enhance ML systems with domain knowledge

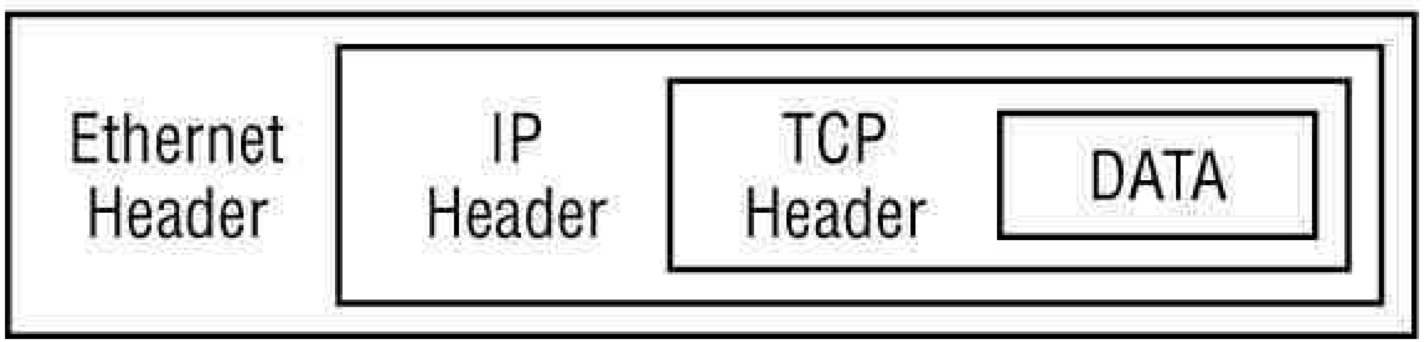
# System framework



# Our case study in cybersecurity

Data

- Network data provided in the form of PCAP files




Network data is often compared to an onion with a header for each layer, followed by the payload.

# Our case study in cybersecurity

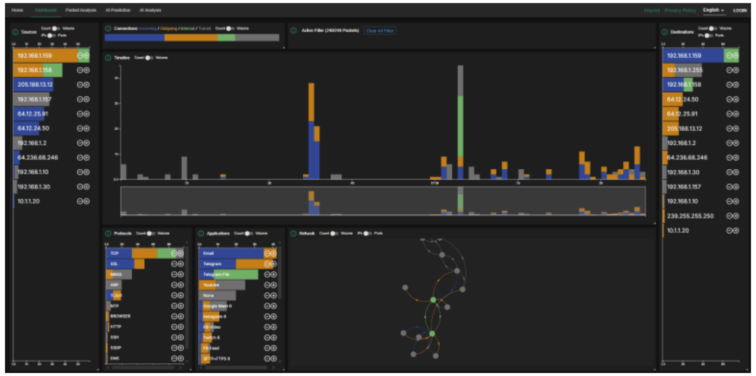
- Data
  - Network data provided in the form of PCAP files
- User
  - Administrators
  - Cybersecurity professionals
  - Malware analysts
- Tasks
  - Develop and enforce security policies and procedures
  - Optimize Quality of Service (QoS)
  - Manage network resources

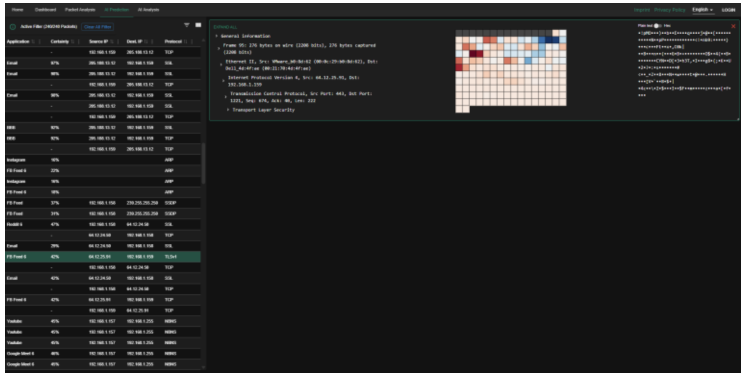
# Progress on our framework

VA

VA+ML+XAI(local)

VA+ML+XAI(global)





# Visual Analytics for Network Packet Captures

**NetCapVis:**
**Web-based Progressive Visual Analytics for Network Packet Captures**

Alex Ulmer* David Sessler† Jörn Kohlhammer‡

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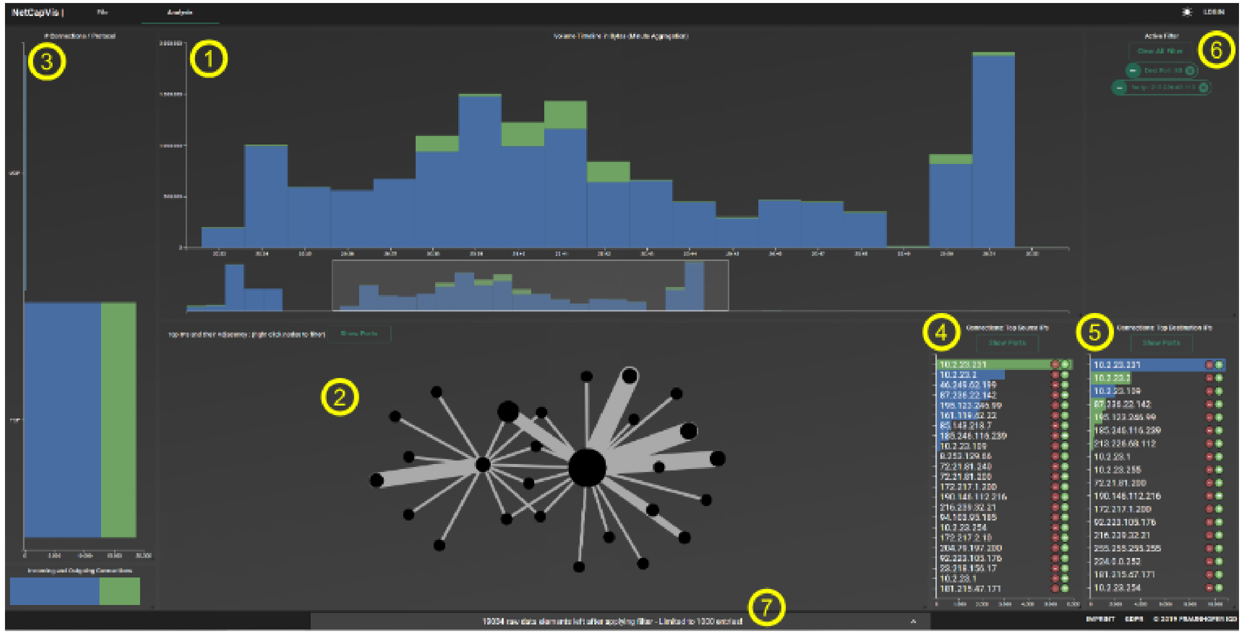
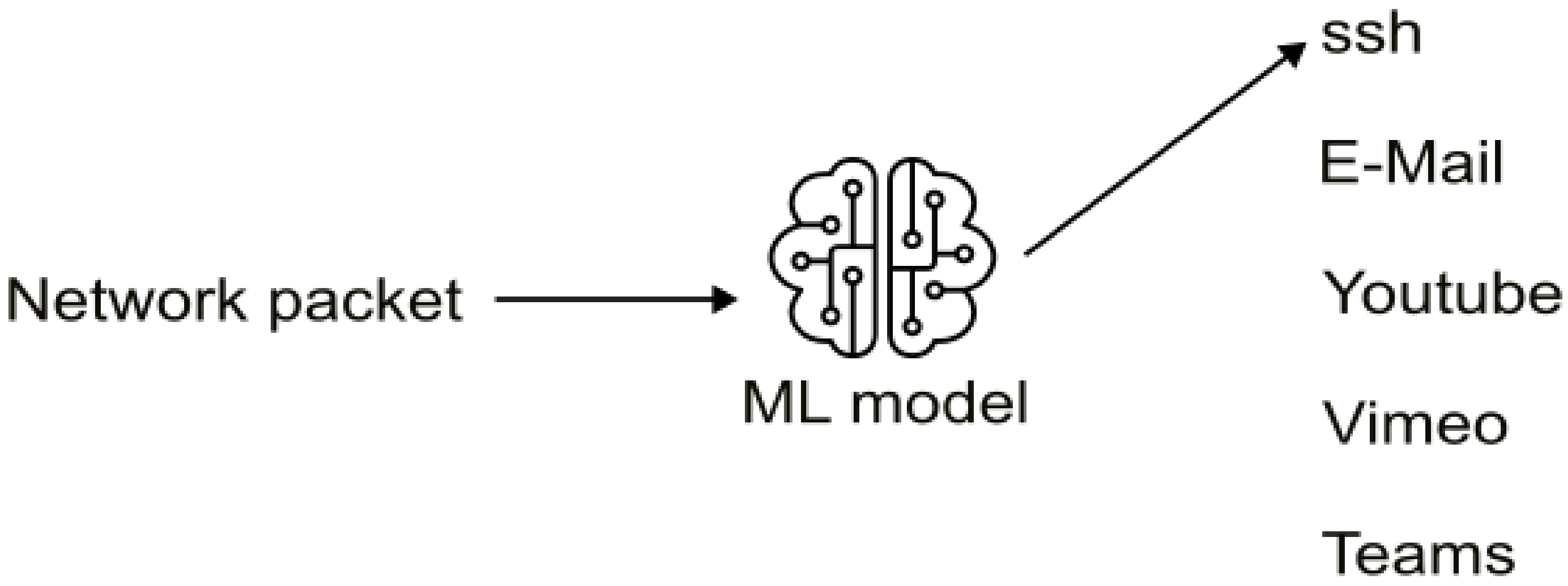
Technische Universität Darmstadt, Germany

- Visual analytics system for analyzing PCAP data
- Parsing of PCAP files
- Interlinked visualization of
- network statistics, including:
  - Network graph
  - Timeline view
  - Bar charts
  - Listing of IP addresses
  and protocols



# ML Integration into the Framework

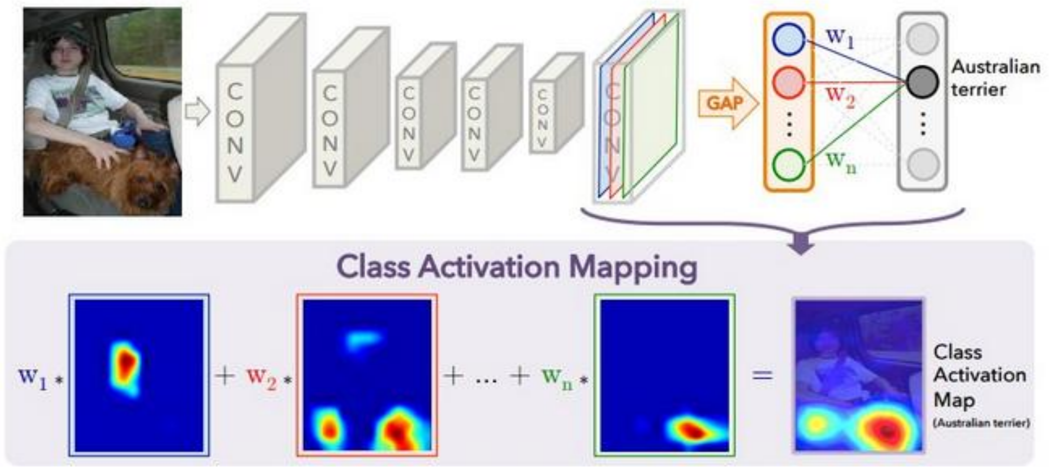


# ML Integration into the Framework

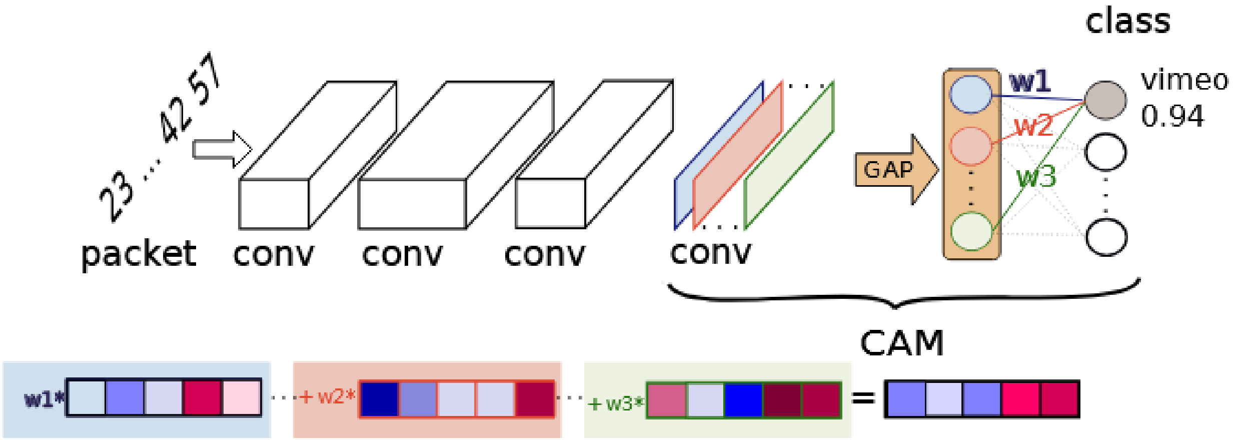
- Researched and compared different ML approaches
  - 1D-CNN model achieved the best performance (confirmed by the field of network research)
- Applied 1D-CNN and evaluated
  - Experimenting with hidden layer depth and width
  - Adjusted convolutional filter sizes
- Created a custom dataset
  - Includes novel and modern application classes (youtube, facebook ...)

# Local XAI Integration into the Framework

- Network packets resemble images, they are one-dimensional, and neighboring bits are frequently related.
- XAI methods from image processing are suitable
  - Class Activation Maps



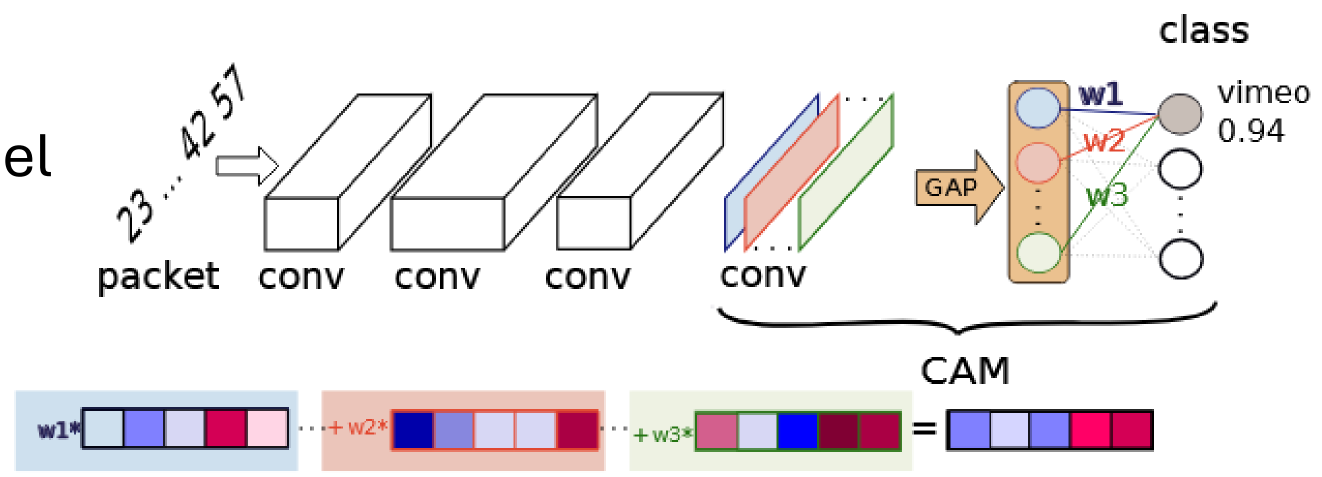

B. Zhou, A. Khosla, A. Lapedriza, A. Oliva and A. Torralba, "Learning Deep Features for Discriminative Localization," *2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*

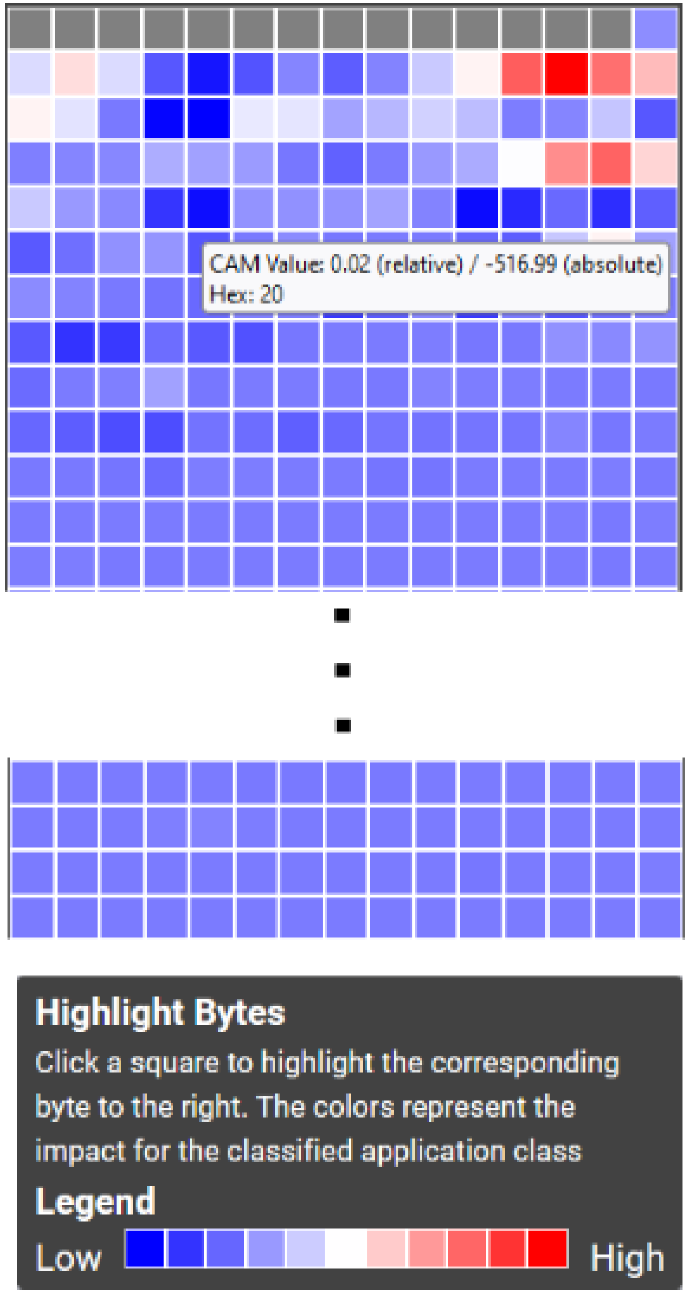


# Local XAI Integration into the Framework

## CAM Calculation:

- The predicted class score is mapped back to the previous convolutional layer to create the CAMs. The resulting CAM is a sum of all convolutional feature maps of the last convolutional layer multiplied by the weights of output layer.
- Computationally cheap
- calculated directly
  on the resulting trained model





CAM Value: 0.02 (relative) / -516.99 (absolute)
Hex: 20
Highlight Bytes
Click a square to highlight the corresponding byte to the right. The colors represent the impact for the classified application class
Legend
Low
High

# Local XAI Integration into the Framework

- Overview of all packets with predicted class
- Packets can be viewed in raw format or as a folded tree structure showing all segments
- Investigation of the most impactful bytes in a PCAP file for a predicted application class.

**Visualization Of Class Activation Maps To Explain AI Classification Of Network Packet Captures**

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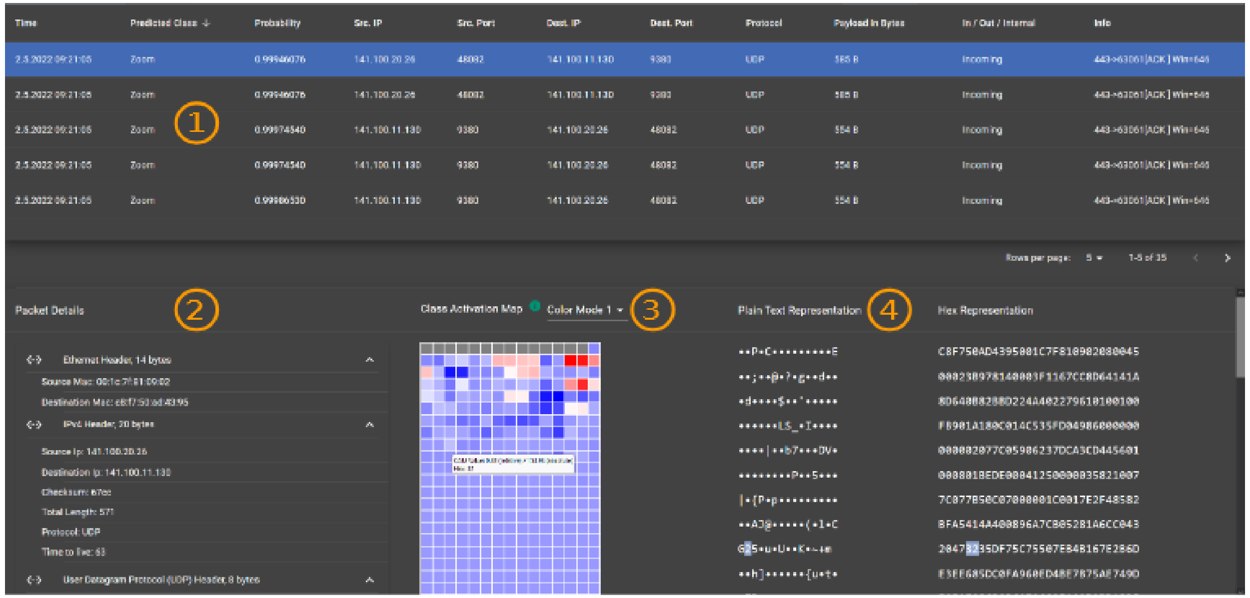
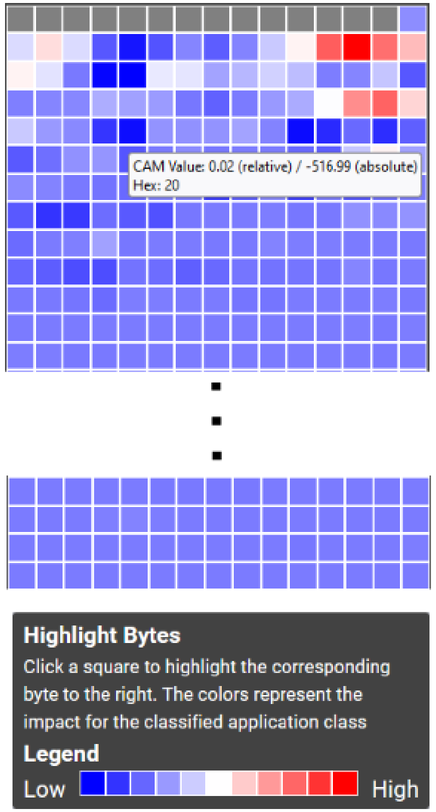


# Local XAI Integration into the Framework

**Findings:**

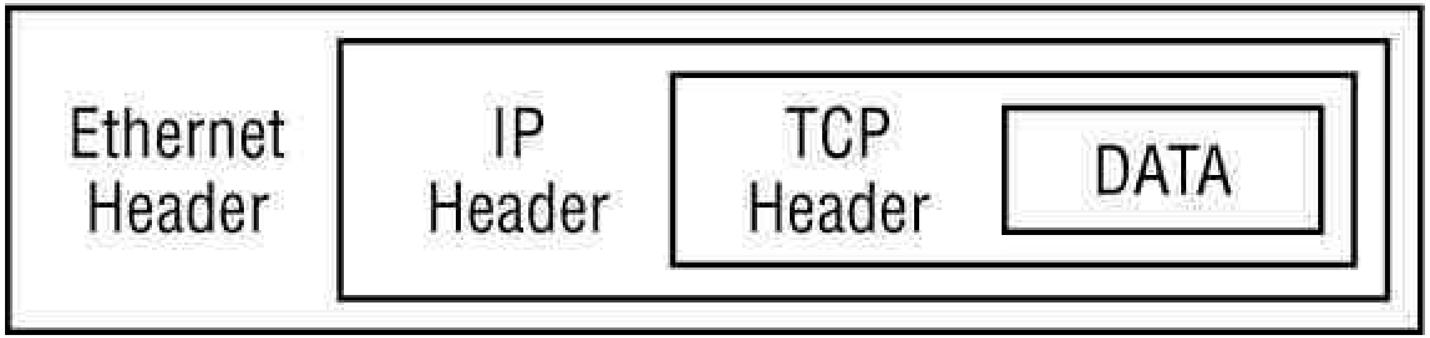
- The model can be simplified without significant performance loss
  - Since the end of the packet is usually encrypted
- Misleading features
  - Sequence number

| Input Size | Accuracy | | |
|---|---|---|---|
| | ISCX2016 | IVA2022 | VNAT2023 |
| 130 | 0.9726 | 0.9872 | 0.9985 |
| 150 | 0.9800 | 0.9853 | 0.9969 |
| 170 | 0.9758 | 0.9887 | 0.9989 |
| 200 | 0.9655 | 0.9836 | 0.9976 |
| 1500 | 0.9586 | 0.9781 | 0.9975 |

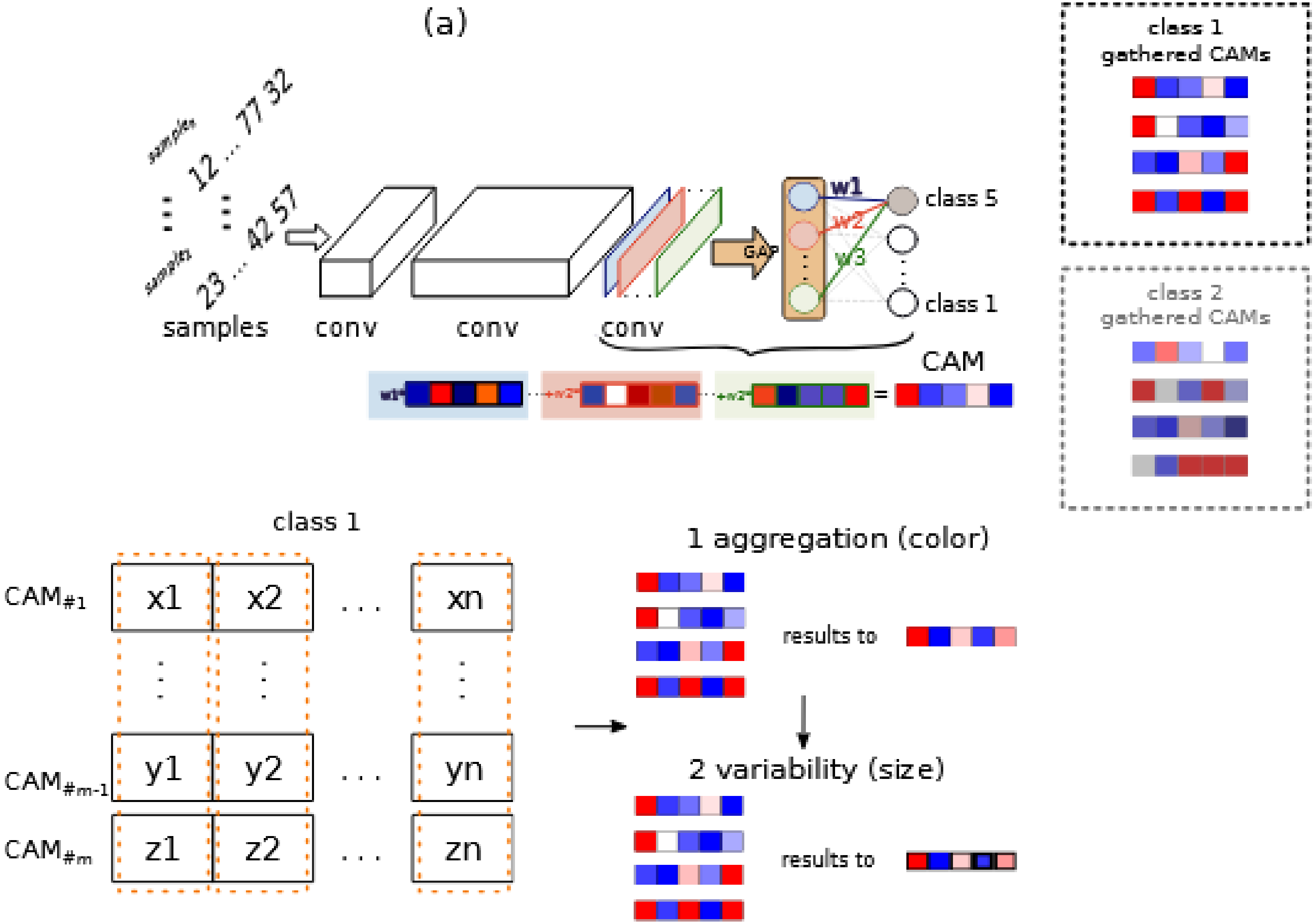


# Global XAI Integration into the Framework

- Position of each unit of information remains constant, lies in its ability to aggregate local explanations for features across all sample



# Global XAI Integration into the Framework



# Global XAI Integration into the Framework

Towards the Visualization of Aggregated Class Activation Maps to Analyse the Global Contribution of Class Features

Igor Cherepanov[1], David Sessler[1], Alex Ulmer[1], Hendrik Lücke-Tieke[1], and Jörn Kohlhammer[1,2]

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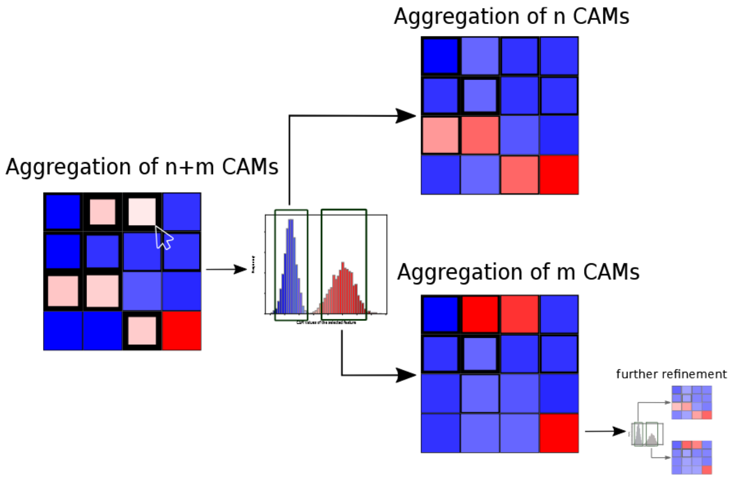


Interactive Analysis of Global Explanations using Aggregated Class Activation Maps for Network Data

I. Cherepanov[1], D. Sessler[1], A. Ulmer [1], F. Wagner[1], T. May [1], J. Kohlhammer[1,2]

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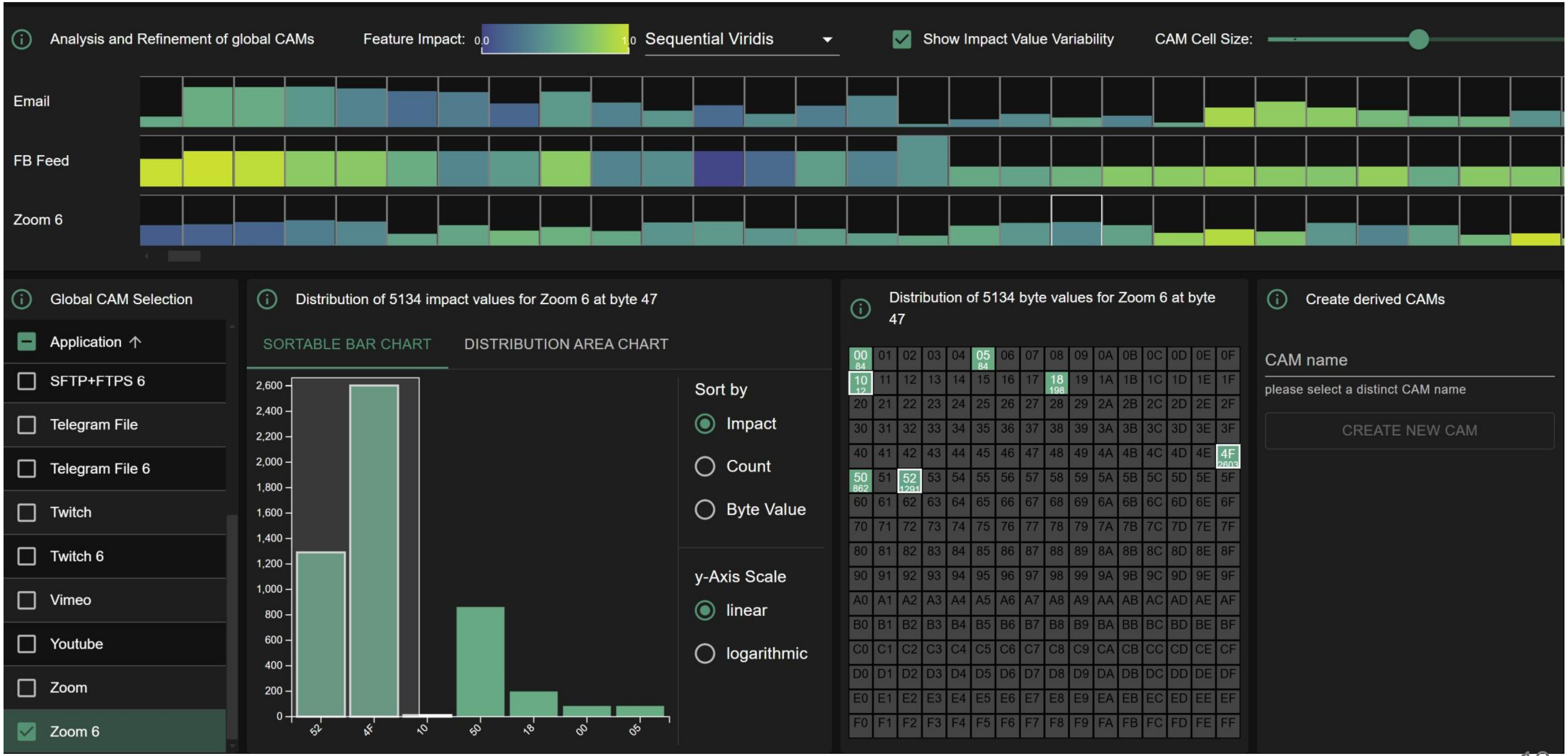
Planned: CGF Submission 2025

# Global XAI Integration into the Framework



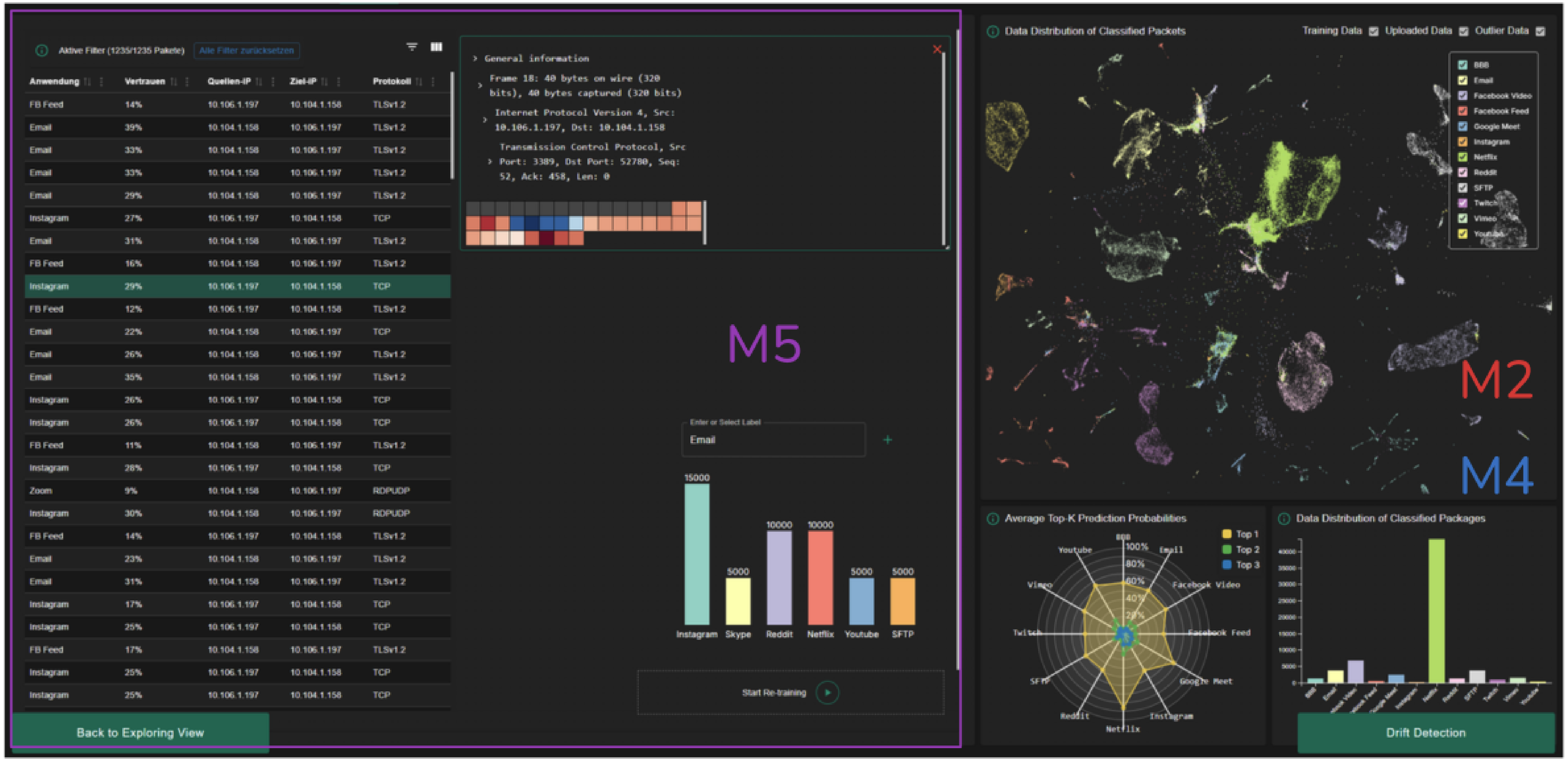
# Global XAI Integration into the Framework

# Enhancement with domain knowledge

Present work:

- Data Drift
  - maintain model accuracy over time
- Evaluation in the domain is challenging due to limited background in simplified ML concepts
  - Challenges in labeling
  - Data drift is difficult for domain experts to understand and interpret
  - Increased complexity when all components (labeling, drift, XAI) are combined

# Enhancement with domain knowledge



# Enhancement with domain knowledge

Future work:

- Model Improvement
  - Applying active learning to iteratively improve the model with informative samples
  - Creation of a more robust model
    - For that we need also a solid dataset as well
- Automatic Rule Extraction/Creation using XAI and raw data
- Providing guidance to help experts overcome the complexity

Thank you for your attention!